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FURTHER STUDY OF INVERSION LAYER MOS SOLAR CELLS

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ABSTRACT

A group of inversion layer MOS solar cells has been fabricated. The highest value of open-circuit voltage obtained for the cells is 0.568V. One of the cells has produced a short-circuit current of 79.6 mA and an open-circuit voltage of 0.54V. It is estimated that the actual area AMO efficiency of this cell is 6.6% with an assumed value of 0.75 for its fill factor. Efforts made for fabricating an IL/MOS cell with reasonable efficiencies are reported. Future work for 4 cm^2 IL cells and 25 cm^2 IL cells is discussed

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INTRODUCTION

In the previous report (1), we presented the experimental results for three IL/MOS solar cells fabricated in the NASA/MSFC laboratory in 1986. The best open-circuit voltage recorded then was 0.465V for one of the cells, while its short-circuit current only had a value of 0.02 mA. In the same report (1), we pointed out that the reasons of getting low short-circuit currents were probably due to (1) the thin interfacial oxide formed by sputtering was too thick and (2) the thermal oxide became too thin at the edge of aluminum to strongly invert the surface.

Efforts have been made to control more accurately the thickness of the thin layer of oxide between aluminum and silicon of the MIS contacts. Using the furnace with 450^{o}C, an oxide layer about 20Å can be grown on a <111> p-type silicon wafer in 20 minutes. This process has improved the open-circuit voltages and the short-circuit currents of the IL cells substantially. One of the 4 cm^2 cells in the fourth run of the experiments has produced 79.6 mA short-circuit current and a value of 0.54V for the open-circuit voltage. An actual area (3.56 cm^2) AM0 efficiency of 6.6% has been achieved with the assumption that the fill factor equals 0.75.

OBJECTIVES

The objectives of this study are (1) fabrication of 4 cm^2 IL/MOS solar cells with good efficiencies (13% AMO efficiency or better), (2) development of a simple, inexpensive, low-temperature process for fabricating high-efficiency IL solar cells and (3) preliminary study of large-area (25 cm^2) IL/MOS solar cells and arrays.

BACKGROUND AND OVERVIEW

The operational principle and the design consideration of IL/MIS solar cells have been discussed in some details in other papers and reports (1)-(7). Here, only a brief review is given.

A. Advantages of the IL Cells

The advantages of IL/MIS solar cells are that the processing is mainly of low temperature and the diffusion-induced crystal damage inherent in diffused p-n junction cells can be avoided. In IL cells, very shallow junctions are formed with high electric field which helps to collect electron-hole pairs generated by short-wavelength light. There is no "dead layer" in this kind of cells. Therefore, their responses for the ultraviolet light are better than those of diffused cells. The IL cells may be possible to have nearly ideal diode properties, which in turn can produce a larger value of open-circuit voltage. The cost of producing the cells can be cut down by using the low temperature processing technology.

B. Design Consideration of IL cells

To have the highest possible efficiency, the structure of an IL cell must be optimized. The most important parameters of the cells for design consideration are (1) the resistivity of the substrate,

(2) the fixed charge in the oxide or other insulators, (3) the number of grids per unit length (usually per cm), and (4) the thickness of the interfacial layer of the thin oxide in an MIS diode.

For an IL cell, the substrate must be p-type with the ⟨111⟩ orientation. The wafers should be doped properly. If it is doped too heavily, it may have difficulty to invert the thin inversion layer beneath the oxide or other insulator; and if it is too lightly doped, the sheet resistance of the inversion layer would be too large. The sheet resistance of the inversion layer can be reduced by increasing the number of grid lines. But too many grid lines would cover too large an area, which would reduce the area exposed to the sunlight. A compromise between these two parameters should be reached by balancing their opposite effects. The thickness of the thin oxide in the MIS contacts plays a very critical role in processing the IL cells. The insulator must be thin enough to guarantee the tunneling effect is sufficient (8). But too thin interfacial layer of the oxide would lead to low open-circuit voltages and would affect the general performance of the cell. Therefore, the thickness of the insulating thin layer should be optimized.

C. Fabrication Process

The fabrication procedures of the IL cells are summerized as follows:

(1) Thermal oxide with a thickness of approximately 1500Å is grown on p-type silicon substrate with ⟨111⟩ crystal orientation.

(2) Metal contact regions are defined using the first mask.

(3) Aluminum is deposited on the back surface and sintered.

(4) The thin oxide in an MIS contact is grown using 450^{o}C furnace for 20 minutes.

(5) Aluminum is evaporated onto the front part of the sample.

(6) Aluminum grid patterns are defined using a second mask.

RESULTS AND DISCUSSION

There were three runs of experiments for the IL cells in the ten weeks period of the 1987 Summer Faculty Fellowship Program. The fourth run was ended on September 15, 1987, about one month after the program was over. The results of the first run were poor due to the accidental etching of the aluminum on the backs of the wafers. In addition the thin layers of oxide in MIS contacts may be too thick because there was no accurate control of the thin oxide at that time. The results of the second run are listed in Table 1 while those of the third run are in table 2.

Both open-circuit voltages and short-circuit currents are much better in the third run than those corresponding values obtained in the first and second runs. In the third run, the aluminum on the back sides was also accidently etched. The worsening contacts in the back sides of the IL cells definitely contributed the bad effects on the short-circuit currents, which are even smaller than their counterparts in the cells fabricated in 1986.

The fourth run was much more successful. The open-circuit voltage of one of the cells equals 0.54V while having a short-circuit current of 79.6 mA. The total area of the cell is about 4 cm^2. The measurements are done under AMO illumination. An actual area (3.56 cm^2) efficiency of 6.8% was estimated with an assumed value of 0.75 for the fill factor of the cell. The result are listed in Table 3.

Note that the oxidation processes with HCl gettering and those without HCl gettering did not make significant difference for the performance of the cells. Therefore, from Run #4 on, we have been using HCl gettering in all oxidation processes.

TABLE 1: EXPERIMENTAL RESULTS OF THE IL/MOS SOLAR CELLS FABRICATED IN RUN NO. 2

Cell No.	Type and Resistivity of Substrate	Number of Grids per cm	Oxide	I_{SC} (mA)	V_{OC} (V)
1A	P <111> 1.19 Ω-cm	121	1544Å (Thermal)	0.002	0.27
1B	P <111> 1.19 Ω-cm	121	1545Å (Thermal)	0.001	0.29
2A	P <111> 1.19 Ω-cm	121	1218Å (Sputtering)	0.005	0.32
2B	P <111> 1.19 Ω-cm	121	1227Å (Sputtering)	0.005	0.002

TABLE 2: EXPERIMENTAL RESULTS OF THE IL/MOS SOLAR CELLS FABRICATED IN RUN NO. 3

Cell No.	Type and Resistivity of Substrate	Number of Grids per cm	Oxide	I_{SC} (mA)	V_{OC} (V)
3	P <111> 1.19 Ω-cm	121	1435Å (With HCl gettering)	0.752	0.539
4	P <111> 1.19 Ω-cm	121	1845Å (With HCl gettering)	0.388	0.283
5	P <111> 1.19 Ω-cm	121	1460Å (With HCl gettering)	0.814	0.568

TABLE 3: EXPERIMENTAL RESULTS OF THE IL/MOS SOLAR CELLS FABRICATED IN RUN NO. 4

Cell No.	Type and Resistivity of Substrate	Number of Grids per cm	Oxide	I_{SC} (mA)	V_{OC} (V)
W1-1	P <111> 1.1 Ω-cm	69	1530Å (With HCl Gettering)	79.6	0.54
W1-2	P <111> 1.1 Ω-cm	69	1535Å (With HCl Gettering)	75.2	0.56
W2-2	P <111> 17 Ω-cm	41	1506Å (With HCl Gettering)	1.6	0.38
W2-3	P <111> 17 Ω-cm	41	1409Å (With HCl Gettering)	52.6	0.482

CONCLUSION AND RECOMMENDATION

A. Conclusion

A group of IL/MOS solar cells have been fabricated in the NASA/MSFC laboratory. One of the cells has a short-circuit current of 79.6 mA and an open-circuit voltage of 0.54V. The actual area (3.56 cm^2) AMO efficiency is estimated to be 6.6% with an assumed value of 0.75 for its fill factor. We conclude that the thin oxide in MIS contacts of the cells has been playing a very critical role to improve the short-circuit currents and even the open-circuit voltages. More efforts, therefore, should be made to control the thickness of the thin oxide (less than 20Å) more accurately. We also conclude that HCl purge is irrelevant to the inversion layer induced in IL cells. Hence, HCl purge is recommended for all oxidation processes.

B. Recommendations:

The future work for the IL cells is recommended as follows:

1. Improvement of the performance of the IL cells so that the 4 cm^2 cells with about 13% AMO efficiency or better could be fabricated. In addition, the cells using sputtering SiO_2 or chemical vapor deposition (CVD) of SiO_2 should be made to get higher oxide charge densities. Also, we have planned to use other insulators such as SiO and Si_3N_4 to establish the inversion layer of an IL cell.

2. Study of smaller area (1 cm^2) IL cells for comparison.

3. Study of large-area (25 cm^2) IL cells and arrays. It is believed that the large area cells can provide large area arrays at lower assembly cost. To study the feasibility of IL/MIS cells for large-scale application, the ability to scale up to large areas for these cells must be explored. Up to now, to the best of our knowledge, there is no literature which has dealt with large-area IL/MIS cells, and the IL cells fabricated are no larger than 4 cm^2. It is believed that our efforts will be significant in developing large silicon solar cells in general and in designing IL/MIS solar cell arrays in particular.

4. Study the large-area IL/MOS solar cell array for space application. The work on 4 cm^2 and 25 cm^2 cells will lay the groundwork of the research for IL solar cell arrays.

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